भारतीय मानक

Indian Standard

IS 2911 (Part 3) : 2021

पाइल नींवों का डिजाइन और निर्माण — रीति संहिता

भाग 3 अंडर-रीम्ड पाइल

(दूसरा पुनरीक्षण)

Design and Construction of Pile Foundations — Code of Practice

Part 3 Under-Reamed Piles

(Second Revision)

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FOREWORD

This Indian Standard (Second Revision) was adopted by the Bureau of Indian Standards, after the draft finalized by the Soil and Foundation Engineering Sectional Committee had been approved by the Civil Engineering Division Council.

Piles find application in foundations to transfer loads from a structure to competent subsurface strata having adequate load-bearing capacity. The load transfer mechanism from a pile to the surrounding ground is complicated and is not yet fully understood, although application of pile foundations is in practice over many decades. Broadly, piles transfer axial loads either substantially by friction along its shaft and/or by the end bearing. Piles are used where either of the above load transfer mechanism is possible depending upon the subsoil stratification at a particular site. Construction of pile foundations require a careful choice of piling system depending upon the subsoil conditions, the load characteristics of a structure and the limitations of total settlement, differential settlement and any other special requirement of a project. The installation of piles demands careful control on position, alignment and depth, and involve specialized skill and experience.

Under-reamed piles are of bored cast *in-situ* and bored compaction concrete types having one or more bulbs formed by suitably enlarging the borehole for the pile shaft. With the provision of bulb(s), substantial bearing or anchorage is available. These piles find application in widely varying situations in different types of soils where foundations are required to be taken down to a certain depth in view of considerations like the need,

a) to avoid the undesirable effect of seasonal moisture changes as in expansive soils;
b) to reach competent strata;
c) to obtain adequate capacity for downward, upward and lateral loads and moments; or
d) to take the foundations below scour level/liquefiable strata.

However, the construction feasibility of under-ream/bulb should be examined as per soil characteristics, particularly in case of clean/river sands.

When the ground consists of expansive soil, for example black cotton soil, the bulb of the under-reamed pile provides anchorage against uplift due to swelling pressure apart from the increased bearing. In case of filled-up or otherwise weak strata overlying the firm strata, enlarged base in the form of under-reamed bulb in firm strata provides larger bearing area and piles of greater bearing capacity can be made. In loose to medium pervious sandy and silty strata, bored compaction piles can also be used, as the process of driving reinforcement cage in the freshly filled concrete in the bore increases the load carrying capacity of the piles. Under-reamed piles may also be used under situations where the vibration and noise caused during construction of piles are to be avoided. The provision of bulb(s) is of special advantage in under-reamed piles to resist uplift and they can be used as anchors.

The recommendations made in this standard are based on the general principles applicable to pile foundations and the experience of construction of a large number of engineering works.

IS 2911 (Part 1) was originally published in 1964 and included provisions regarding driven cast *in-situ* piles, precast concrete piles, bored piles and under-reamed piles including load testing of piles. Subsequently the portion pertaining to under-reamed pile foundations was deleted and covered in IS 2911 (Part 3) : 1980 ‘Code of practice for design and construction of pile foundations: Part 3 Under-reamed pile foundations (*first revision*)’. At that time, it was also decided that the provisions regarding other types of piles should also be published separately for ease of reference and to take into account the recent developments in this field. Consequently, Part 1 of this standard was revised in 1979 into three sections. Later, in 1984, a new section as (Part 1/Sec 4) was introduced in this part of the standard to cover the provisions of bored precast concrete piles. IS 2911 (Part 1/Sections 1 to 4) were again revised in 2010. The portion relating to load test on piles has been covered in a separate part, namely, IS 2911 (Part 4) : 2013 ‘Design and construction of pile foundations — Code of practice: Part 4 Load test on piles (*second revision*)’.

Considerable assistance was provided by CSIR-Central Building Research Institute, Roorkee, for including the provisions on under-reamed piles in the first version of this standard, and thereafter in bringing out the separate standard for under-reamed piles in 1980. This revision of the standard (Part 3) has been brought out to bring it in line with other parts of this standard which have since been revised in 2010 and to align the provisions with the design and construction practices prevalent in the field.

(*Continued to third cover*)

Indian Standard

DESIGN AND CONSTRUCTION OF PILE FOUNDATIONS — CODE OF PRACTICE

PART 3 UNDER-REAMED PILES

(Second Revision)

1 SCOPE

1.1 This standard (Part 3) covers the design and construction of under-reamed piles having one or more bulb(s) formed along the pile shaft.

1.1.1 This standard covers under-reamed piles of maximum depth up to 10 m.

2 REFERENCES

The Standards listed below contain provisions which through reference in this text, constitute provision of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards:

IS No.	*Title*
269 : 2015	Ordinary Portland cement — Specification (*sixth revision*)
455 : 2015	Portland slag cement — Specification (*fifth revision*)
456 : 2000	Plain and reinforced concrete — Code of practice (*fourth revision*)
875 (Part 3) : 2015	Design loads (other than earthquake) for buildings and structures — Code of practice: Part 3 Wind loads (*third revision*)
1489	Portland pozzolana cement — Specification
(Part 1) : 2015	Fly ash based (*fourth revision*)
(Part 2) : 2015	Calcined clay based (*fourth revision*)
1498 : 1970	Classification and identification of soils for general engineering purposes (*first revision*)
1786 : 2008	High strength deformed steel bars and wires for concrete reinforcement — Specification (*fourth revision*)
1892 : 2021	Subsurface investigation for foundations — Code of practice (*second revision*)
1893 (Part 1) : 2016	Criteria for earthquake resistant design of structures: Part 1 General provisions and buildings (*sixth revision*)
2720	Methods of test for soils
(Part 5) : 1985	Determination of liquid and plastic limit (*second revision*)
(Part 40) : 1977	Determination of free swell index of soils
2911 (Part 4) : 2013	Design and construction of pile foundations — Code of practice: Part 4 Load test on piles (*second revision*)
2974 (Part 1) : 1982	Code of practice for design and construction of machine foundations: Part 1 Foundation for reciprocating type machines (*second revision*)
4968 (Part 2) : 1976	Method for subsurface sounding for soils: Part 2 Dynamic method using cone and bentonite slurry (*first revision*)
6403 : 1981	Code of practice for determination of bearing capacity of shallow foundations (*first revision*)
8041 : 1990	Specification for rapid hardening Portland cement (*second revision*)
8043 : 1991	Hydrophobic Portland cement — Specification
12330 : 1988	Specification for sulphate resisting Portland cement
12600 : 1989	Portland cement, low heat — Specification

3 TERMINOLOGY

For the purpose of this standard, the following definitions shall apply.

3.1 Allowable Load — The load which may be applied to a pile after taking into account its ultimate load capacity, group effect, the allowable settlement, negative skin friction and other relevant loading conditions.

3.2 Anchor Pile — An anchor pile means a pile meant for resisting pull or uplift forces.

3.3 Batter Pile (Raker Pile) — The pile which is installed at an angle to the vertical using temporary casing or permanent liner.

3.4 Bored Cast *in-situ* Pile — Piles formed by boring a hole in the ground by percussive or rotary method with the use of temporary/permanent casing or drilling mud and subsequently filling the hole with reinforced concrete.

3.5 Bored Compaction Pile — A bored cast *in-situ* pile with or without bulb(s) in which the reinforcement cage is driven by suitable method in the freshly filled concrete in the bore. If the pile is with bulb(s), it is known as 'under-reamed bored compaction pile'.

3.6 Cut-off Level — It is the level where a pile is cut-off to support the pile caps or beams or any other structural components at that level.

3.7 Elastic Displacement— This is the magnitude of the displacement of the pile head during rebound on removal of a given test load. This comprises two components,

a) elastic displacement of the soil participating in load transfer; and
b) elastic displacement of the pile shaft.

3.8 Factor of Safety — It is the ratio of the ultimate load capacity of a pile to the safe load on the pile.

3.9 Gross Displacement — The total movement of the pile top under a given load.

3.10 Initial Load Test — In this test, a test pile is tested to determine the load carrying capacity of the pile by loading either to its ultimate load or to two and half times the estimated safe load.

3.11 Initial Test Pile — One or more piles, which are not working piles, may be installed if required to assess the load-carrying capacity of a pile. These piles are tested either to their ultimate load capacity or to two and half times the estimated safe load.

3.12 Load Bearing Pile — A pile formed in the ground for transmitting the load of a structure to the soil by the resistance developed at its tip and/or along its surface. It may be formed either vertically or at an inclination (batter pile) and may be required to resist uplift forces.

If the pile supports the load primarily by resistance developed at the pile tip or base, it is called 'End bearing pile' and, if primarily by friction along its surface, then 'Friction pile'.

3.13 Multi-Under-Reamed Pile — An under-reamed pile having more than one bulb. The pile having two bulbs is known as double under-reamed pile.

3.14 Net Displacement — The net vertical movement of the pile top after the pile has been subjected to a test load and subsequently released.

3.15 Routine Load Test — A working pile is subjected to load testing for a test load up to 1.5 times the safe load.

3.16 Safe Load — It is the load derived by applying a factor of safety on the ultimate load capacity of the pile or as determined from load test.

3.17 Ultimate Load Capacity — The maximum load which a pile can carry before failure, that is, when the founding strata fails by shear as evidenced from the load settlement curve or the pile fails as a structural member.

3.18 Under-Reamed Pile — A bored *cast in-situ* or bored compaction concrete pile with an enlarged bulb(s) made by either cutting or scooping out the soil or by any other suitable process.

3.19 Working Load — The load assigned to a pile as per design.

3.20 Working Pile — A pile forming part of the foundation system of a given structure.

4 NECESSARY INFORMATION

4.1 For the satisfactory design and construction of bored cast *in-situ* and bored compacted under-reamed piles and pile foundation, the information on the following aspects is necessary:

a) Site investigation data as laid down in IS 1892 or any other relevant Indian Standard. Sections of trial borings, supplemented wherever appropriate by penetration tests, should incorporate data/information down to depth sufficiently below the anticipated level of founding of piles but this should generally be not less than 5 m beyond the pile founding level. Adequacy of the bearing strata should be ensured by supplementary tests, if required.
b) The nature of the soil both around and beneath the proposed pile should be indicated on the basis of appropriate tests of strength, compressibility, etc. Ground water level and conditions such as artesian

conditions, if any, should also be recorded. Results of chemical tests to ascertain the sulphate, chloride and any other deleterious chemical content of soil and water should be indicated.

c) A qualitative indication of the degree of expansiveness of soil is given in Annex A. The free swell index of soil should be determined in accordance with IS 2720 (Part 40).

d) In case rock is encountered, adequate description of the rock to convey its physical conditions as well as its strength characteristics should be indicated.

In case of weathered rock, adequate physical description and its expected physical behaviour on boring should be indicated.

e) General plan and cross-section of the building showing type of structural frame, including basement, if any, in relation to the proposed pile cap top levels.

f) The general layout of the structure showing estimated loads and moments at the top of pile caps but excluding the weight of the piles and caps should be provided. The top levels of finished pile caps shall also be indicated.

g) All transient loads due to seismic, wind, water current, etc, are to be indicated separately.

h) Sufficient information about structures existing nearby should be provided.

j) In soils susceptible to liquefaction during earthquake which shall be ascertained as per IS 1893 (Part 1), appropriate analysis may be done to determine the depth of liquefaction and consider the pile depth accordingly.

4.2 As far as possible, all information in **4.1** shall be made available to the agency responsible for the design and/or construction of piles and/or foundation work.

4.3 The design details of pile foundation shall give the information necessary for setting out and layout of piles, cut-off levels, finished cap level, layout and orientation of pile cap in the foundation plan and the safe capacity of each type of pile, etc.

4.4 Due note shall be taken of the experience of under-reamed and other piles in the area close to the proposed site and any soil strata report thereof.

5 EQUIPMENT AND ACCESSORIES

5.1 The selection of equipment and accessories would depend upon the type of under-reamed piles chosen for a job after giving due considerations to the subsoil strata, ground water condition, types of founding material and the required penetration therein. Also it will depend on economic considerations and availability of manually or power operated equipment.

5.2 A typical list of equipment for manual construction is given in Annex B.

5.3 Bore holes may be made by earth augers. In case of manual boring, an auger boring guide shall be used to keep the bores vertical or to the desired inclination and in position.

After the bore is made to the required depth, enlarging of the base shall be carried out by means of an under-reaming tool.

5.4 Stabilization of bore holes may be done either by circulation or by keeping bore full of drilling mud (bentonite).

5.5 In ground with high water table having unstable pile bores, boring and under-reaming may be carried out using a suitable drilling mud. Requirements for bentonite drilling mud are given in **8.4**. In normally met soil strata, drilling mud can be poured from top while boring and under-reaming can be done by normal spiral earth auger and under-reamer. The level of drilling mud should always be about one metre above water table or the level at which caving in occurs. In case of very unstable strata with excessive caving in, continuous circulation of drilling mud using suitable pumping equipment and tripod, etc, alongwith modified auger and under-reamer may be used.

5.6 To avoid irregular shape and widening of bore hole in very loose strata at top, a casing pipe of suitable length may be used temporarily during boring and concreting.

5.7 For improved control over the inclination of batter piles, a tripod hoist with fixed pulley should be used for lowering in of under-reaming tools.

5.8 For placing the concrete in bore holes full of drilling mud or subsoil water, tremie pipe of not less than 100 mm diameter should be used.

5.9 For batter under-reamed piles, the reinforcement cage should be placed guiding it by a chute or any other suitable method. If concreting is not done by tremie, it should be done by chute.

5.10 In under-reamed bored compaction piles, suitable devices should be used for guiding the movement of drop weight and specified core assembly for its driving. For operating the drop weights, suitable winch of adequate capacity with hoisting attachment should be used.

5.11 Kentledge

Kentledge should be used as dead weight for applying test load on a pile.

6 DESIGN CONSIDERATIONS

6.1 General

Under-reamed pile foundations shall be designed in such a way that the load from the structure they support, can be transmitted to the sub-surface with adequate factor of safety against shear failure of sub-surface and without causing such settlement (differential or total), which may result in structural damage and/or functional distress under permanent/transient loading. The pile shaft should have adequate structural capacity to withstand all loads (vertical compression, uplift, lateral) and moments which are to be transmitted to the subsoil and shall be designed according to IS 456.

6.1.1 In expansive soils, the minimum length of piles shall be 3.5 m below ground level. In case of expansive soil deposits of shallow depth overlying non-expansive competent strata or rock, piles of shorter length can also be provided.

However, in case of high to very high expansive soils, due care shall be taken to establish the minimum depth of pile with the top-most (first) bulb located below the level of significant moisture variations/active zone.

6.1.2 The diameter of under-reamed bulbs may vary from 2 to 2.5 times shaft diameter depending upon the feasibility of construction and design requirements. In bored cast *in-situ* under-reamed piles and under-reamed bored compaction piles, the bulb diameter shall be normally 2.5 and 2 times the shaft diameter, respectively.

6.1.3 The spacing of bulbs should not be less than 1.5 times the diameter of bulb.

6.1.4 The first bulb should be at a minimum depth of 2 times the bulb diameter below ground level or cut-off level, whichever is lower.

6.1.5 Under-reamed piles with more than two bulbs are not advisable without ensuring their feasibility in strata needing stabilization of boreholes by drilling mud. The number of bulbs in case of under-reamed bored compaction piles should not exceed two in such strata.

6.1.6 The minimum diameter of pile shaft shall be 250 mm. However, in case of strata/ground water consisting of excessive chemicals such as sulphates and chlorides, or piles with tremie concreting, the minimum diameter of the pile shaft shall be 300 mm.

6.1.7 Under-reamed batter piles in dry soil conditions can be constructed with batter not exceeding 15°.

6.1.8 The construction feasibility of under-ream/ bulb should be examined as per soil characteristics, particularly in case of clean/river sands.

6.1.9 For guidance, typical details of bored cast *in-situ* under-reamed pile foundations are shown in Fig. 1.

6.1.10 *Adjacent Structures*

6.1.10.1 When working near existing structures, care shall be taken to avoid damage to such structures. IS 2974 (Part 1) may be used as a guide for studying qualitatively the effect of vibration on persons and structures.

6.1.10.2 In case of deep excavations adjacent to piles, proper shoring or other suitable arrangement shall be made to guard against undesired lateral movement of soil.

6.2 Design of Piles

The load carrying capacity of under-reamed piles depends mainly on the pile dimensions and soil strata. Axial load on a pile is transmitted by point bearing at the tip and the projected area of the bulb(s), and skin friction along the pile shaft. Depending upon the nature of soil and pile geometry, in addition to the skin friction on shaft, friction can develop on the soil cylinder between the extreme bulbs. In under-reamed bored compaction piles, the mechanism of load transfer remains the same but soil properties along the shaft improved by the process are considered. In uplift load, point bearing component at tip is absent but unlike other straight shaft piles, point bearing on an annular projection of the bulb is present. Lateral load and moment are sustained by horizontal soil reaction developed along the pile length, which depends on several factors.

The design of piles shall be such that it has an adequate factor of safety,

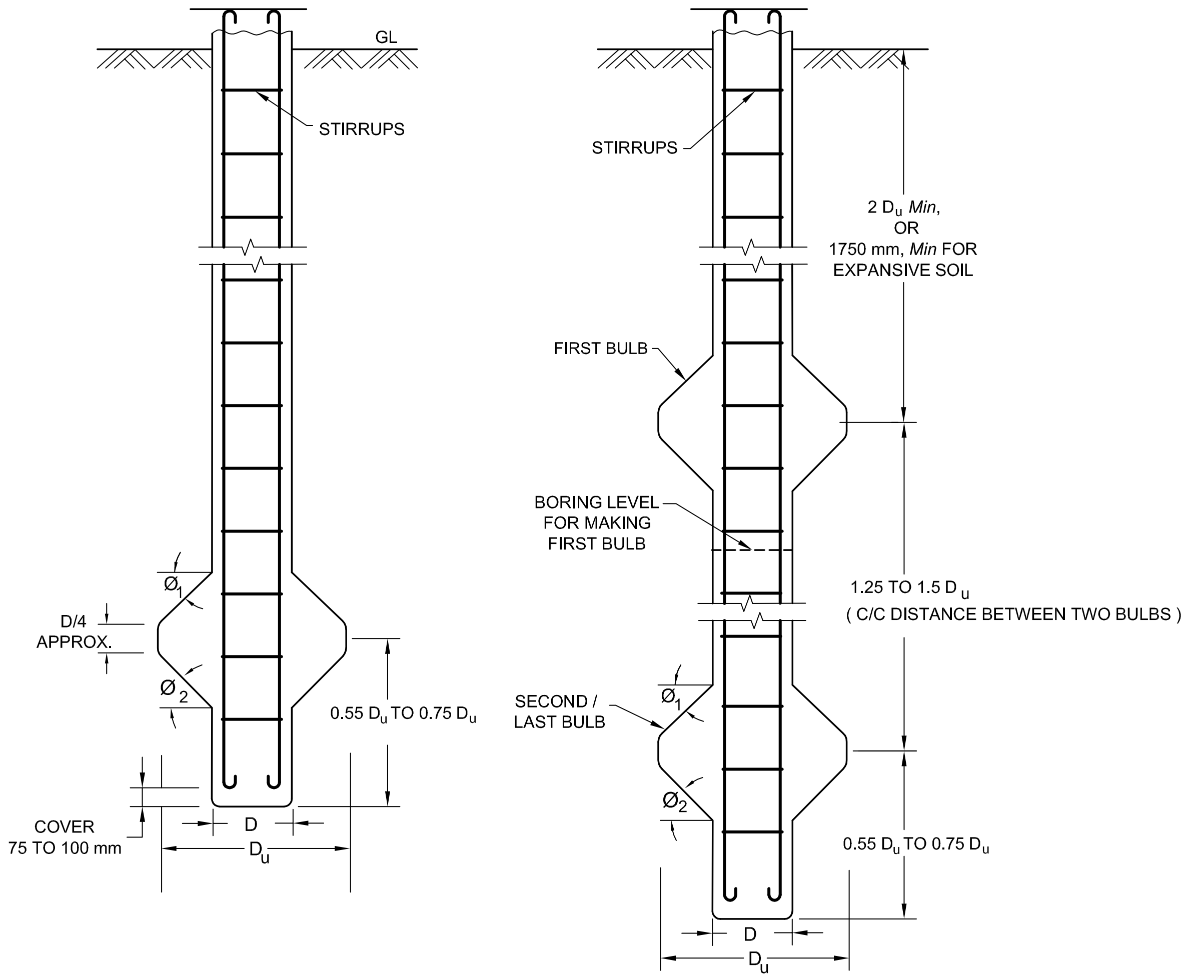
a) as a structural member to transmit the imposed loads;
b) against failure of strata due to reaching ultimate strength. Further, it should ensure that the desired limit of settlement is not exceeded;
c) the pile capacities shall be established/confirmed by initial load tests as per IS 2911 (Part 4).

6.2.1 *Pile as a Structural Member*

The pile should have adequate strength to sustain the design loads. The pile cross-section should be checked for combined effect of vertical loads (compressive and uplift) and/or lateral loads and moments. The pile shaft should be designed as a short/long column considering both concrete and steel (*see* **6.2.2**) as per IS 456, unless otherwise specified in this standard. In case of latter, the permissible increase in stresses shall be taken for wind load and seismic forces [*see* IS 875 (Part 3) and IS 1893 (Part 1)].

6.2.2 *Reinforcement in Piles*

6.2.2.1 The design of reinforcement depends upon the installation conditions. The nature of the subsoil and the nature of load to be transmitted by the shaft-axial, or otherwise. The design shall be in accordance with **6.2.1**. However, the minimum area of longitudinal reinforcement shall be 0.4 percent of the cross-sectional area of the pile shaft and shall be provided throughout the length.


GL
STIRRUPS
Ø1
D/4 APPROX.
Ø2
0.55 Du TO 0.75 Du
COVER 75 TO 100 mm
D
Du
STIRRUPS
2 Du Min, OR 1750 mm, Min FOR EXPANSIVE SOIL
FIRST BULB
BORING LEVEL FOR MAKING FIRST BULB
1.25 TO 1.5 Du (C/C DISTANCE BETWEEN TWO BULBS)
SECOND / LAST BULB
Ø1
Ø2
0.55 Du TO 0.75 Du
D
Du

$Ø_1$= 45° APPROX, $Ø_2$= 30°- 45° APPROX, D_u = 2.5 D NORMALLY

1A SECTION OF SINGLE UNDER-REAMED PILE

1B SECTION OF MULTI-UNDER-REAMED PILE

All dimensions in millimetres.

Fig. 1 Typical Details of Bored Cast *in-situ* Under-Reamed Pile Foundations

6.2.2.2 The main reinforcement of the pile shall extend above cut-off level for at least the development length to be embedded into the pile cap/grade beam.

6.2.2.3 The minimum diameter of the rings shall be 8 mm and the spacing of the rings shall be not less than 150 mm. Stiffener rings of suitable diameter and spacing should be provided in the reinforcing cage to impart adequate rigidity to the reinforcing cage during handling and installation. Stiffener rings preferably of 12 mm diameter at every 1.5 m centre to centre spacing should be provided along the entire length of the cage. Minimum 6 numbers of vertical bars shall be used for a circular pile and minimum diameter of vertical bar shall be 12 mm. The minimum clear horizontal spacing between the adjacent vertical bars shall be four times the maximum aggregate size in concrete. If required, the bars can be bundled to maintain such spacing.

6.2.2.4 Clear cover to all reinforcement including rings in pile shaft shall be not less than 50 mm, which shall be increased to 75 mm in case of aggressive environment of sulphates, etc. In addition, the clear cover of the main reinforcement from the pile tip shall be 75 mm to 100 mm.

6.2.3 *Safe Load*

Safe load on a pile shall be taken as the least of the following,

a) By calculating ultimate load from soil properties and applying suitable factor of safety;

b) By load test on pile as provided in IS 2911 (Part 4); and

c) By working out safe load as per Annex C considering soil data.

6.2.3.1 *Ultimate load capacity (using the static formula)*

The ultimate load capacity of a pile can be calculated from soil properties. The soil properties required are strength parameters, cohesion, angle of internal friction and soil density. If these properties are not available directly from laboratory and field tests, they may be indirectly obtained from *in-situ* penetration test data [*see* IS 4968 (Part 2) and IS 6403]. The success of the approach essentially depends how realistically the soil properties are determined or deduced.

a) *Cohesive soils*

For cohesive soils the ultimate load carrying capacity of an under-reamed pile may be worked out from the following expressions:

$$Q_u = A_p.N_c C_p + A_a.N_c.C'_a + C'_a.A'_s + \alpha.C_a.A_s$$

where

Q_u = ultimate load capacity of pile, in kN;

A_p = cross-sectional area of pile tip, in m^2;

N_c = bearing capacity factor, may be taken as 9;

C_p = average cohesion at pile tip, in kN/m^2;

A_a = $\pi/4\ (D_u^2 - D^2)$ where D_u and D are the under-reamed and shaft diameter, in m, respectively;

C'_a = average cohesion of soil around the under-reamed bulbs, in kN/m^2;

α = adhesion factor layer depending on the consistency of soil (*see* Note 4);

C_a = average cohesion of the soil along the pile shaft, in kN/m^2;

A_s = surface area of the shaft (to be taken above under-reamed bulb), in m^2; and

A'_s = surface area of the cylinder circumscribing the under-reamed bulbs, in m^2.

The above expression holds for the usual spacing of under-reamed bulbs spaced at not more than one-and-a-half times their diameter.

NOTES

1 The first two terms in formula are for end bearing and the last two for friction components.

2 If the pile is with one bulb only, the third term will not occur.

3 For calculating uplift load, first term will not occur in formula.

4 The value of adhesion factor α depends on the undrained shear strength of the clay, and may be obtained from Fig. 2.

b) *Granular soils*

For granular soils the following expression be used,

$$Q_u = A_p.\left(\frac{1}{2}.D.\gamma.N_\gamma + \gamma.d_f.N_q\right) + A_a\frac{1}{2}.D_u.n.\gamma.N_\gamma$$

$$+ \gamma.N_q\sum_{r=1}^{r=n} d_r + \frac{1}{2}.\pi.D.\gamma.K \tan\delta \times \left(d_1^2 + d_f^2 - d_n^2\right)$$

where

A_p = $\pi/4\ D^2$, in m^2 (where D is shaft diameter, in m);

A_a = $\pi/4\ (D_u^2 - D^2)$, in m^2 (where D_u is the under-reamed bulb diameter, in m);

n = number of under-reamed bulbs;

γ = average unit weight of soil (submerged unit weight in strata below water table), in kN/m^3;

N_γ and N_q = bearing capacity factors depending upon the angle of internal friction (*see* Notes 3 and 4);

d_r = depth of the centre of different under-reamed bulbs below ground level, in m;

d_f = total depth of pile below ground level, in m;

K = earth pressure coefficient (usually taken as 1.75 for sandy soils);

δ = angle of wall friction (may be taken equal to the angle of internal friction $\emptyset$);

d_1 = depth of the centre of first under-reamed bulb, in m; and

d_n = depth of the centre of the last under-reamed bulb, in m.

NOTES

1 The first two terms in the formula are for bearing component and the last one for friction component.

2 For uplift bearing on tip, will not occur.

3 N_γ factor can be taken for general shear failure according to IS 6403.

4 N_q applicable for bored piles are given in Fig. 3.

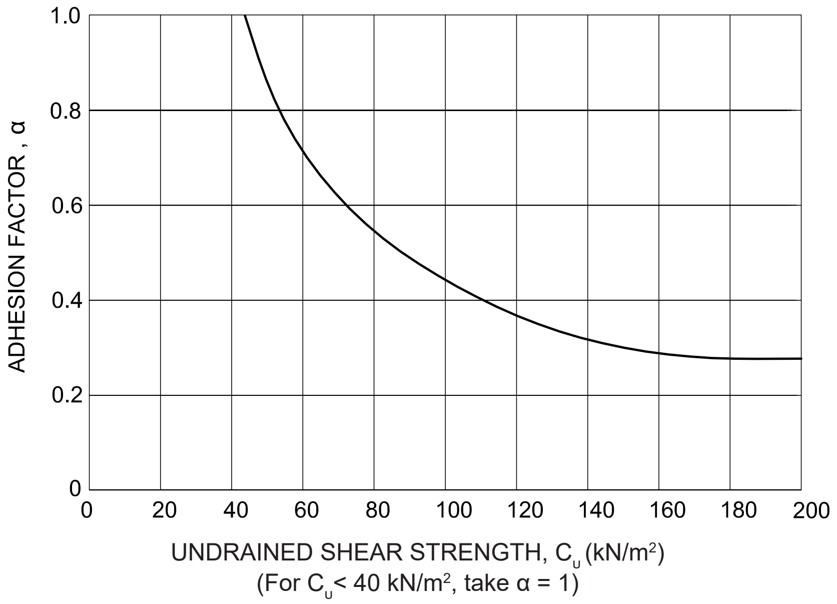


FIG. 2 VARIATIONS OF α WITH C_u

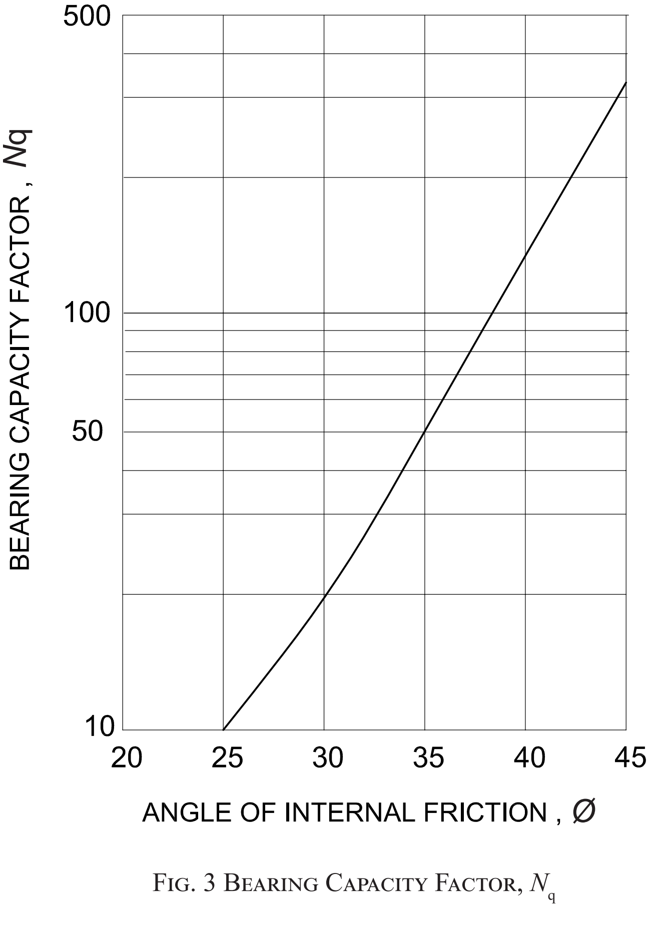


FIG. 3 BEARING CAPACITY FACTOR, N_q

c) *Soil strata having both cohesion and friction*

In soil strata having both cohesion and friction or in layered strata having two types of soil, the bearing capacity may be estimated using pile capacity derived from both the formula. However, in such cases the load tests will be a better guide [*see* IS 2911 (Part 4)].

d) *Under-reamed bored compaction piles in sandy/silty (non-plastic/low plastic) strata*

For under-reamed bored compaction piles in sandy/silty (non-plastic/low plastic) strata, the formula in **6.2.3.1** (b) shall be applicable but the modified value of $\emptyset$ will be used as given below:

$$\emptyset_1 = (\emptyset + 40)/2$$

where

$\emptyset$ = angle of internal friction of virgin soil.

The values of N_γ, N_q and δ are taken corresponding to $\emptyset_1$.

The value of the earth pressure coefficient K will be 3.

e) *Factors of safety*

Factor of safety should be chosen after considering,

1) the reliability of the calculated value of ultimate load capacity of a pile,
2) the types of superstructure and the type of loading, and
3) allowable total/differential settlement of the structure.

When the ultimate load capacity is determined from static formula, the factor of safety would depend on the reliability of the formula and the reliability of the subsoil parameters used in the computation. The minimum factor of safety on static formula shall be 3. The final selection of a factor of safety shall take into consideration the load settlement characteristics of the structure as a whole at a given site.

Higher value of factor of safety for determining the safe load on piles may be adopted, where,

i) settlement is to be limited or unequal settlement avoided,
ii) large impact or vibrating loads are expected, and
iii) the properties of the soil may deteriorate with time.

6.2.3.2 *Pile load tests*

The safe load on pile(s) in compression, uplift and lateral shall be determined by carrying out load test on piles in accordance with IS 2911 (Part 4). There should be a minimum of two numbers of initial pile load tests for first 200 piles and additional one test for every additional 200 piles and part thereof. The frequency of testing stipulated above is applicable for each diameter of pile and rated capacity of pile in each type (mode) of loading. The number of tests may be increased if the strata is erratic and for important structures.

6.2.3.3 *Safe load as per Annex C*

Safe load should be worked out as per Annex C considering the soil data.

NOTE — Safe loads as given in the above referred table are symptomatic. Safe load carrying capacity of pile shall be worked out as per **6.2.3**.

6.2.3.4 *Permissible increase over safe vertical compression load on piles*

a) *Overloading*

When a pile in a group, designed for a certain safe load is found, during or after execution, to fall just short of the load required to be carried by it, an overload up to 10 percent of the pile capacity may be allowed on each pile. The total overloading on the group should not, however, be more than 10 percent of the capacity of the group subject to the increase of the load on any pile being not more than 25 percent of the allowable load on a single pile.

b) *Transient loading*

The maximum permissible increase over the safe load of a pile, as arising out of wind loading, is 25 percent. In case of loads and moments arising out of earthquake effects, the increase of safe load on a single pile may be limited to the provisions contained in IS 1893 (Part 1). For seismic forces, under-reamed piles shall be treated as point bearing piles. The seismic and wind forces shall not be considered to act simultaneously. For transient loading arising out of superimposed loads, no increase is allowed.

6.2.4 *Negative Skin Friction or Drag Down Force*

When a soil stratum through which a pile shaft has penetrated into an underlying hard stratum, compresses as a result of either it being unconsolidated or it being under a newly placed fill or as a result of remoulding during installation of the pile, a drag-down force is generated along the pile shaft up to a point in depth where the surrounding soil does not move downward relative to the pile shaft. Existence of such a phenomenon shall be assessed and the allowable load shall be suitably reduced, subject to the condition that the under-ream/bulb is provided below the strata susceptible to negative skin friction.

6.2.5 *Lateral Load on Piles*

A pile may be subjected to lateral force from a number of causes, such as wind, earthquake, earth pressures, effect of moving vehicles, plant and equipment, etc. The lateral load carrying capacity of a single pile depends not only on the horizontal subgrade modulus of the surrounding soil but also on the structural strength of the pile shaft against bending consequent upon application of a lateral load. While considering lateral load on piles, effect of other co-existent loads including the axial load on the pile should be taken into consideration for checking the structural capacity of the shaft. The method for pile capacity analysis under lateral load is given in Annex D.

Because of limited information on horizontal subgrade modulus of soil and pending refinements in the theoretical analysis, it is suggested that the adequacy of a design should be confirmed by pile load tests. In the zone susceptible to liquefaction which shall be determined in accordance with IS 1893 (Part 1), the lateral resistance of the soil shall not be considered.

6.2.5.1 *Fixed and free head conditions*

A group of three or more pile connected by a rigid pile cap shall be considered to have fixed head condition. Caps for single piles must be interconnected by grade beams in two directions and for twin piles by grade beams in a line transverse to the common axis of the pair so that the pile head is fixed. In all other conditions the pile shall be considered as free head condition.

6.2.6 *Batter Piles (Raker Piles)*

Raker piles are normally provided where vertical piles cannot resist the required applied horizontal forces. In the preliminary design, the load on a raker pile is generally considered to be axial. The distribution of load between raker and vertical piles in a group may be determined by graphical or analytical methods. Where necessary, due consideration should be made for secondary bending induced as a result of the pile cap movement, particularly when the cap is rigid. Free standing raker piles are subjected to bending moments due to their own weight or external forces from other causes. Raker piles, embedded in fill or consolidating deposits, may become laterally loaded owing to the settlement of the surrounding soil.

Under-reamed piles can be constructed with batter not exceeding 15° with vertical.

6.2.7 *Spacing of Piles*

6.2.7.1 Spacing of piles shall be considered in relation to the nature of ground, the types of piles and the manner in which the piles transfer the load to the ground.

6.2.7.2 Generally, the centre to centre spacing for cast *in-situ* under-reamed piles in a group is two times the bulb diameter ($2D_u$), however, it shall not be less than 1.5 D_u. The maximum spacing of piles should generally not exceed 3 m. If the adjacent piles are of different diameter, the value of larger bulb diameter shall be considered. The centre to centre spacing for under-reamed bored compaction piles is generally 1.5 times the bulb diameter (1.5 D_u).

6.2.8 *Pile Groups*

6.2.8.1 In order to determine the load-carrying capacity of a group of piles, a number of efficiency equations are in use. However, it is difficult to establish the accuracy of these efficiency equations as the behaviour of pile group is dependent on many complex factors. It is desirable to consider each case separately on its own merits.

6.2.8.2 The load-carrying capacity of a pile group may be equal to or less than the load-carrying capacity of individual piles multiplied by the number of piles in the group.

6.2.8.3 In load bearing walls, piles should generally be provided under all wall junctions to avoid point loads on beams.

6.3 Grade Beams

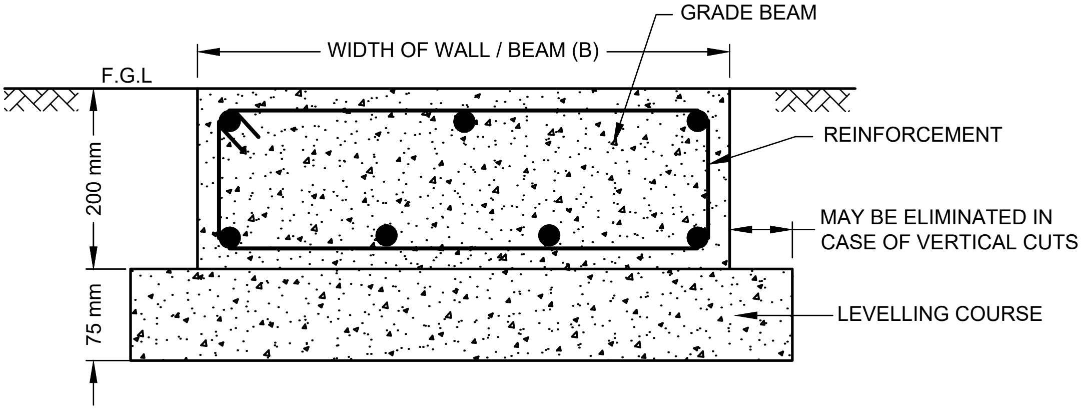
6.3.1 The grade beams supporting the load bearing walls shall be designed taking due account of arching effect due to masonry above beam. The beam with masonry due to composite action behaves as a deep beam.

For the design of grade beams, maximum bending moment of $wl^2/30$, where w is uniformly distributed load per metre run and l is the effective span in metres, shall be considered. For considering composite action, the minimum height of wall shall be 0.6 times the pile spacing. The brick strength should not be less than 3 N/mm^2. For concentrated loads and other loads which come directly over the beam, full bending moment should be considered.

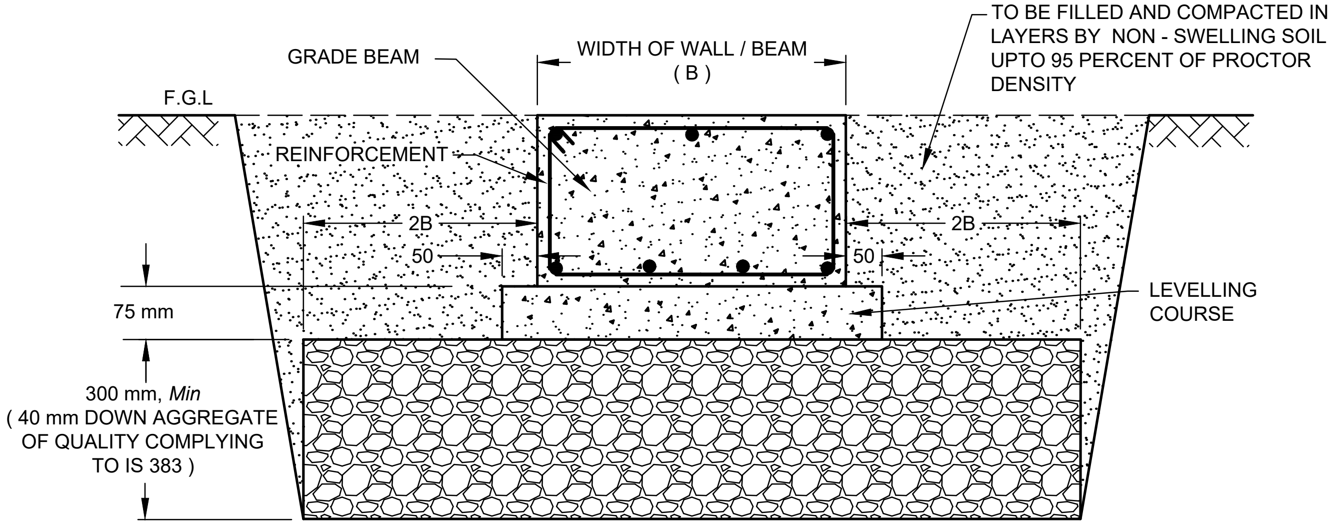
6.3.2 The minimum overall depth of grade beams shall be 200 mm. An equal amount of reinforcement shall be provided at the bottom and top of the beam. The longitudinal reinforcement both at bottom and top should not be less than three bars of 12 mm diameter with clear cover of 50 mm. Spacing of stirrups of 8 mm diameter bars should not be more than the depth of grade beam.

6.3.3 In expansive soils, the grade beams and 75 mm levelling concrete course shall be provided over 40 mm down gravel layer/mechanically stabilized mix (MSM) layer having a minimum compacted thickness of 300 mm and minimum width equal to five times the width of grade beams (*see* Fig. 4).

6.3.4 In case of exterior beams over piles in expansive soils, plinth protection with proper slope shall be provided.



4A Grade Beam in Non-Expansive Soils


TO BE FILLED AND COMPACTED IN LAYERS BY NON - SWELLING SOIL UPTO 95 PERCENT OF PROCTOR DENSITY
GRADE BEAM
WIDTH OF WALL / BEAM (B)
F.G.L
REINFORCEMENT
2B
2B
50
50
75 mm
LEVELLING COURSE
300 mm, Min (40 mm DOWN AGGREGATE OF QUALITY COMPLYING TO IS 383)

All dimensions in millimetres

4B Grade Beam in Expansive Soils

Fig. 4 Typical Sections of Grade Beam

6.4 Design of Pile Cap

6.4.1 The pile caps may be designed by assuming that the load from column or pedestal is dispersed at 45° from the top of the cap to the mid depth of the pile cap from the base of the column or pedestal. The reaction from piles may also be taken to be distributed at 45° from the edge of the pile, up to the mid-depth of the pile cap. On this basis, the maximum bending moment and shear forces should be worked out at critical sections. The method of analysis and allowable stresses and structural design should be in accordance with IS 456.

6.4.2 The pile cap shall be deep enough to allow for necessary anchorage of the column and pile reinforcement.

6.4.3 The pile cap should be rigid enough so that the imposed load could be distributed on the piles in a group equitably.

6.4.4 In case of a large cap, where differential settlement may occur between piles under the same cap, due consideration for the consequential moment should be given.

6.4.5 The clear overhang of the pile cap beyond the outer most pile in the group shall be a minimum of 150 mm.

6.4.6 The cap is generally cast over a 75 mm thick levelling course of concrete. The clear cover for main reinforcement in the pile cap shall not be less than 60 mm.

6.4.6.1 In expansive soils, the pile cap and 75 mm levelling concrete course shall be provided over 40 mm down gravel layer/mechanically stabilized mix (MSM) layer having a minimum compacted thickness of 300 mm and extending minimum 150 mm beyond the pile cap.

6.4.7 The embedment of pile into cap should be 75 mm.

7 MATERIALS

7.1 Cement

The cement used shall be any of the following and the type selected should be appropriate for the intended use:

a) Ordinary Portland cement conforming to IS 269,
b) Rapid hardening Portland cement conforming to IS 8041,
c) Portland slag cement conforming to IS 455,
d) Portland pozzolana cement (fly ash based) conforming to IS 1489 (Part 1),
e) Portland pozzolana cement (calcined clay based) conforming to IS 1489 (Part 2),
f) Hydrophobic cement conforming to IS 8043,
g) Low heat Portland cement conforming to IS 12600, and
h) Sulphate resisting Portland cement conforming to IS 12330.

The other requirements as specified in IS 456 shall also be complied with.

7.2 Reinforcement

The reinforcement shall be high strength deformed steel bars conforming to IS 1786. The other requirements as specified in IS 456 for reinforcing bars shall also be complied with.

7.2.1 For under-reamed bored compaction piles, the reinforcement cage shall be fabricated by spot welding the rings with main reinforcement to withstand the stresses during driving process.

7.3 Concrete

7.3.1 Consistency of concrete to be used for cast *in-situ* under-reamed piles shall be consistent with the method of installation of piles. Concrete shall be designed as per IS 456 so as to have homogeneous mix having a slump/workability consistent with the method of concreting under the given conditions of pile installation.

7.3.2 The slump should be between 150 mm and 200 mm at the time of pouring.

7.3.3 The minimum grade of concrete to be used for under-reamed piles shall be M 25. For sub-aqueous concrete, the requirements specified in IS 456 shall be followed. The minimum cement content shall be 400 kg/m^3 in all conditions. The concrete for piles in aggressive surroundings due to presence of sulphates, etc, should have a concrete mix of appropriate type of cement in suitable proportion as per IS 456.

7.3.4 For the concrete, water and aggregates specifications laid down in IS 456 shall be followed in general.

7.3.5 For tremie concreting, aggregates having nominal size more than 20 mm should not be used.

7.3.6 For under-reamed bored compaction piles rapid hardening cement (*see* **7.1**) shall not be used.

8 CONSTRUCTION

8.1 Under-reamed piles may be constructed by selecting suitable installation techniques at a given site depending on subsoil strata conditions and type of under-reamed pile and number of bulbs. The construction feasibility of under-ream/bulb should particularly be examined in case of sand, clean/river sands.

8.2 In construction with the equipment given in **5**, initially boring guide is fixed with its lower frame levelled for making desired angular adjustment for piles at batter. Boring is done up to required depth and under-reaming is completed.

8.2.1 In order to achieve proper under-reamed bulb, the depth of bore hole should be checked before starting under-reaming. It should also be checked during under-reaming and any extra soil at the bottom of bore hole removed by auger before reinserting the under-reaming tool.

8.2.2 The completion of desired under-reamed bulb is ascertained by,

a) the vertical movement of the handle; and when no further soil is cut; or
b) by any other suitable method.

8.2.3 In double or multi-under-reamed piles, boring is first completed to the depth required for the first (top) under-ream only and after completing under-reaming, boring is extended further for the second under-ream and the process is repeated.

8.2.4 In a pile group, number of under-ream/bulb should be same.

8.3 Control of Piling Installation

8.3.1 Under-reamed piles should be installed by installation technique, covering,

a) the manner of borehole stabilization, that is, use of drilling mud;

b) manner of concreting; and

c) choice of boring tools in order to permit satisfactory installation of a pile at a given site. Detailed information about the subsoil conditions is essential to determine the installation technique.

8.3.2 *Control of Alignment*

Piles shall be installed as accurately as possible according to the design and drawings either vertically or to the specified batter. Greater care should be exercised in respect of installation of single piles or piles in two-pile groups. As a guide, for vertical pile a deviation of 1.5 percent and for raker pile a deviation of 4 percent should not be exceeded. Piles should not deviate more than 75 mm or $D/6$ whichever is less from their designed positions at the cut-off level. In the case of single pile under a column the positional deviation should not be more than 50 mm or $D/6$ whichever is less. In case of piles deviating beyond these limits and to such an extent that the resulting eccentricity cannot be taken care of by redesign of the pile cap or grade beam, the piles shall be replaced or supplemented by additional piles.

8.4 Use of Drilling Mud

8.4.1 The drilling mud to be used for stabilizing the borehole in bored piling work should conform to the requirements given in Annex E.

8.4.2 In case a borehole is stabilized by use of drilling mud, the specific gravity of the mud suspension should be determined at regular intervals by a suitable slurry sampler. Consistency of the drilling mud shall be controlled throughout the boring as well as concreting operations in order to keep the hole stabilized as well as to avoid concrete getting mixed up with the thicker suspension of the mud.

8.4.3 The concreting operations should not be taken up when the specific gravity of bottom slurry is more than 1.12. The slurry should be maintained at minimum 1.5 m above the ground water level.

8.5 Cleaning Boreholes

If a borehole is stabilized by drilling mud, the bottom of the hole shall be cleaned of all loose and undesirable materials by augering before commencement of concreting.

8.6 Concreting

8.6.1 Concreting as per IS 456 shall be done as soon as possible after completing the pile bore. The bore hole full of drilling mud should not be left unconcreted for more than 12 to 24 h depending upon the stability of bore hole.

8.6.2 In case the pile bore is stabilized with drilling mud or by maintaining water head within the bore hole, the bottom of bore hole shall be carefully cleaned by augering or suitable means and pile bore shall be checked for its depth before concreting. In such cases, concreting shall be done by tremie method.

8.6.3 The following requirements shall be followed for tremie concrete work:

a) The concrete should be coherent, rich in cement (not less than 400 kg/m^3) and of slump between 150 mm and 200 mm;

b) The tremie should be water tight throughout its length and have a hopper attached to its head by a water tight connection;

c) The tremie pipe should be large enough in relation to the size of the aggregate. For 20 mm down aggregate, the tremie pipe should have a diameter not less than 100 mm;

d) The tremie pipe should always be kept full of concrete and should always remain at least 1 m into the concrete in the bore hole with adequate margin against accidental withdrawal of tremie pipes;

e) The pile should be concreted wholly by tremie and the method of deposition should not be changed midway to prevent laitance from being entrapped within the pile; and

f) All tremie pipes should be cleaned before and after use.

8.6.4 Normally concreting of the piles should be uninterrupted. In exceptional cases of interruption of concreting, it shall be resumed within 1 or 2 h. In case such an interruption is made while using tremie method of concreting, the tremie shall not be taken out of the concrete. Instead it shall be raised and lowered from time to time to prevent the concrete around the tremie from setting.

8.6.5 In case of withdrawal of tremie out of the concrete, either accidentally or to remove a choke in the tremie, the tremie may be reintroduced in a manner to prevent impregnation of laitance or scum lying on the top of the concrete already deposited in the bore and concreting resumed as mentioned in **8.6.4**. The fresh concrete will emerge out of the tremie displacing the laitance and scum and prevent impregnation or laitance of scum in the fresh concrete.

8.6.6 For under-reamed bored compaction piles, the pile bore is first filled up with concrete without placing any reinforcement. Soon after, the specified core assembly shall be driven and extra concrete shall be poured in simultaneously to keep the level of concrete up to the desired level.

8.6.7 The top of concrete in a pile shall be brought above the cut-off level to permit removal of all laitance and weak concrete before capping and to ensure good concrete at the cut-off level. The reinforcing cages shall be left with adequate protruding length above cut-off level for proper embedment into the pile cap.

8.6.8 Where cut-off level is less than 1.5 m below working level, concrete shall be cast to a minimum of 300 mm above cut-off level. For each additional 0.3 m increase in cut-off level below the working level, additional coverage of minimum 50 mm shall be allowed. Higher allowance may be necessary depending on the length of the pile. When concrete is placed by tremie method, it shall be cast up to the ground level to permit overflow of concrete for visual inspection or to a minimum of one metre above cut-off level. In the circumstances where cut-off level is below the ground water level, the need to maintain a pressure on the unset concrete equal to or greater than water pressure should be observed and accordingly length of extra concrete above cut-off level shall be determined.

8.6.9 Sampling, testing and acceptance criteria shall be as per IS 456.

8.7 Defective Pile

8.7.1 In case, defective piles are formed, they shall be left in place. Additional piles as necessary shall be provided.

8.7.2 Any deviation from the designed location, alignment or load capacity of a pile shall be noted and adequate measures taken well before the concreting of the pile cap and plinth beams.

8.7.3 While removing excess concrete or laitance above the cut-off level, chipping by manual or pneumatic tools shall be permitted seven days after pile casting. However, good concrete is to be ensured at cut-off level by pouring fresh concrete after removal of all the weak concrete.

8.8 Estimation of Concrete Quantity

After concreting, the actual quantity of concrete shall be compared with the average obtained from observations made in the case of a few piles already cast. If the actual quantity is found to be considerably less, the matter should be investigated and appropriate measures taken.

NOTE — If the estimates of concrete consumption is on the volume of bore holes and not on the basis of concrete quantity actually consumed, the concrete used may be found smaller than estimated and cement consumption may work out to be less.

8.9 Recording of Pile Details

8.9.1 A daily site record shall be maintained for the installation of piles and shall essentially contain the following information:

a) Date of installation including sequence of installation in case of piles in a group;
b) Number and dimension of the pile including length and diameter of shaft and bulbs, number of bulbs, type of pile, reinforcement details, grade of concrete, slump and mark of the pile;
c) Depth bored and depth of under-ream/bulb;
d) Time taken for boring, concreting and empty boring, chiseling and whether the pile is wet or dry;
e) Cut-off level and working level;
f) Sample bore log in the initial stage or when major variation occur;
g) When drilling mud is used, specific gravity of the fresh supply and contaminated mud in the bore hole before concreting shall be recorded regularly;
h) Method of boring;
j) Ground water level; and
k) Any other important observation.

8.9.2 Typical data sheet for facility of recording pilling data is shown in Annex F.

ANNEX A

[*Clause* 4.1 (c)]

DEGREE OF EXPANSIVENESS

A-1 The degree of expansiveness and consequent damage to the structures with light loading may be qualitatively judged as per Table 8 of IS 1498.

A-1.1 In areas of soil showing high or very high differential free swell values, conventional shallow strip footings may not be adequate.

ANNEX B

(*Clause* 5.2)

EQUIPMENT FOR UNDER-REAMED PILES (MANUAL CONSTRUCTION)

B-1 EQUIPMENT

B-1.1 Normally the following equipment will be required in manual operation:

a) An auger;
b) An under-reamer;
c) A boring guide; and
d) Accessories like spare extensions, cutting tool, concreting funnel, etc.

B-1.1.1 For the piles of size larger than 300 mm and for larger depths additional equipment required will be a portable tripod hoist with a manually operated winch.

B-1.1.2 For piles in high ground water table and unstable soil conditions, boring and under-reaming shall be carried out with bentonite slurry using suitable equipment. Tremie pipe shall be used for concreting.

B-1.1.3 The additional equipment normally required for under-reamed bored compaction pile are the following:

a) Drop weight for driving the core assembly; and
b) Pipe or solid core.

ANNEX C

(*Clauses* 6.2.3 *and* 6.2.3.3)

SAFE LOAD ON UNDER-REAMED PILES

C-1 SAFE LOAD TABLE

Safe loads as given in Table 1 are symptomatic. Safe load carrying capacity of pile shall be worked out as per **6.2.3**.

C-1.1 The safe bearing, uplift and lateral loads for under-reamed piles given in Table 1 apply to both medium compact ($10 < N < 30$) sandy soils and clayey soils of medium ($4 < N < 8$) consistency including expansive soils. The values are for piles with bulb diameter equal to 2.5 times the shaft diameter (N denotes corrected SPT value).

Col 4 and Col 5 of Table 1 provide the minimum pile lengths for single and double under-reamed piles, respectively, in deep deposit of expansive soils. The values given for double under-reamed piles in Col 7 and Col 11 are only applicable in expansive soils.

C-1.5 For dense sandy ($N \geq 30$) and stiff clayey ($N \geq 8$) soils, the safe loads in compression and uplift obtained from Table 1 may be increased by 25 percent. The lateral thrust values should not be increased unless the stability and strength of top soil (strata up to a depth of about three times the pile shaft diameter) is ascertained and found adequate. For piles in loose ($4 < N \leq 10$) sandy and soft ($2 < N \leq 4$) clayey soils, the safe loads should be taken 0.75 times the values shown in the Table. For very loose ($N \leq 4$) sandy and very soft ($N \leq 2$) clayey soils, the values obtained from the Table should be reduced by 50 percent.

C-1.6 The safe loads obtained from Table 1, should be reduced by 25 percent if the pile bore holes are full of subsoil water or drilling mud during concreting. No such reduction may be done if the water is confined to the shaft portion below the bottom-most bulb.

C-1.7 The safe loads in uplift and compression given in Table 1 or obtained in accordance with **C-1.2** to **C-1.6** should be reduced by 15 percent for piles with bulb of twice the shaft diameter. But no such reduction is required for lateral loads shown in Table 1.

C-1.8 The safe loads for under-reamed bored compaction piles can be worked out by increasing the safe load of equivalent bored *cast in-situ* under-reamed pile obtained from Table 1 by 1.5 times in case of medium ($10 < N < 30$) and 1.75 times in case of loose to very loose ($N \leq 10$) sandy soils. Depending upon the nature and initial compactness of strata, pile geometry and lay-out of piles, this increase may be up to a factor of 2. The values of lateral loads should not be increased by more than 1.5 times in all cases. In obtaining safe load of under-reamed bored compaction pile the reduction for pile bore holes full of subsoil water or drilling mud during concreting should be taken 15 percent instead of 25 percent as given in **C-1.6**. The reduction for piles with twice the bulb diameter is to be taken 10 percent instead of 15 percent as given in **C-1.7**.

Table 1 Safe Load for Vertical Bored Cast *in-situ* Under-Reamed Piles in Sandy and Clayey Soils Including Black Cotton Soils

(*Clause* C-1)

Sl No.	Size		Length		Compression				Safe Loads in Uplift Resistance				Lateral Thrust	
	Dia-meter of Pile	Under-reamed Dia-meter	Single Under-reamed	Double Under-reamed	Single Under-reamed	Double Under-reamed	Increase per 30 cm Length	Decrease per 30 cm Length	Single Under-reamed	Double Under-reamed	Increase per 30 cm Length	Decrease per 30 cm Length	Single Under-reamed	Double Under-reamed
	mm	mm	m	m	t	t	t	t	t	t	t	t	t	t
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
i)	250	625	3.5	3.5	12	18	1.15	0.9	6	9	0.85	0.70	1.5	1.8
ii)	300	750	3.5	3.5	16	24	1.4	1.1	8	12	1.05	0.85	2.0	2.4
iii)	375	940	3.5	3.75	24	36	1.8	1.4	12	18	1.35	1.10	3.0	3.6
iv)	400	1 000	3.5	4.0	28	42	1.9	1.5	14	21	1.45	1.15	3.4	4.0
v)	450	1 125	3.5	4.5	35	52.5	2.15	1.7	17.5	25.75	1.60	1.30	4.0	4.8
vi)	500	1 250	3.5	5.0	42	63	2.4	1.9	21	31.5	1.80	1.45	4.5	5.4

ANNEX D

(*Clause* 6.2.5)

ANALYSIS OF LATERALLY LOADED UNDER-REAMED PILES

D-1 GENERAL

D-1.1 The ultimate resistance of a vertical pile to a lateral load and the deflection of the pile as the load builds up to its ultimate value are complex matters involving the interaction between a semi-rigid structural element and soil which deforms partly elastically and partly plastically. The failure mechanisms of an infinitely long pile and that of a short rigid pile are different. The failure mechanisms also differ for a restrained and unrestrained pile head conditions.

Because of the complexity of the problem only a procedure for an approximate solution that is adequate in most of the cases is presented here. Situations that need a rigorous analysis shall be dealt with accordingly.

D-1.2 The first step is to determine, if the pile will behave as a short rigid unit or as an infinitely long flexible member. This is done by calculating the stiffness factor *R* or *T* for the particular combination of pile and soil.

Having calculated the stiffness factor, the criteria for behaviour as a short rigid pile or as a long elastic pile are related to the embedded length *L* of the pile. The depth from the ground surface to the point of virtual fixity is then calculated and used in the conventional elastic analysis for estimating the lateral deflection and bending moment.

D-2 STIFFNESS FACTORS

D-2.1 The lateral soil resistance for granular soils/normally consolidated clays which have varying soil modulus is modeled according to the equation:

$$\frac{p}{y} = \eta_h z$$

where

p = lateral soil reaction per unit length of pile at depth z below ground level;

y = lateral pile deflection; and

η_h = modulus of subgrade reaction for which the recommended values are given in Table 2.

D-2.2 The lateral soil resistance for over-consolidated clays with constant soil modulus is modeled according to the equation:

$$\frac{p}{y} = K$$

where

$$K = \frac{k_1}{1.5} \times \frac{0.3}{B}$$

where k_1 is Terzaghi's modulus of subgrade reaction as determined from load deflection measurements on a 30 cm square plate and B is the width of the pile (diameter in case of circular piles). The recommended values of k_1 are given in Table 3.

Table 2 Modulus of Subgrade Reaction for Granular Soils/Normally Consolidated Clays, η_h, kN/m^3

(*Clause* D-2.1)

Sl No.	Soil Type	*N* (Blows/30 cm)	Range of η_h kN/m^3 × 10^3	
			Dry	Submerged
(1)	(2)	(3)	(4)	(5)
i)	Very loose sand	0 – 4	< 0.4	< 0.2
ii)	Loose sand	4 – 10	0.4 – 2.5	0.2 – 1.4
iii)	Medium sand	10 – 35	2.5 – 7.5	1.4 – 5.0
iv)	Dense sand	> 35	7.5 – 20.0	5.0 – 12.0

NOTE — The η_h values may be interpolated for intermediate standard penetration values, *N*.

Table 3 Modulus of Subgrade Reaction for Over-consolidated Clay, k_1, KN/m^3

(*Clause* D-2.2)

Sl No.	Soil Consistency	Unconfined Compression Strength, q_u kN/m^2	Range of k_1 kN/m^3 × 10^3
(1)	(2)	(3)	(4)
i)	Soft	25 – 50	4.5 – 9.0
ii)	Medium stiff	50 – 100	9.0 – 18.0
iii)	Stiff	100 – 200	18.0 – 36.0
iv)	Very stiff	200 – 400	36.0 – 72.0
v)	Hard	> 400	> 72.0

NOTE — For q_u less than 25, k_1 may be taken as zero, which implies that there is no lateral resistance.

D-2.3 Stiffness Factors

D-2.3.1 *For Piles in Granular Soils/Normally Consolidated Clays*

$$\text{Stiffness factor } T\text{, in m} = \sqrt[5]{\frac{EI}{\eta_h}}$$

where

E = Young's modulus of pile material, in MN/m^2;

I = moment of inertia of the pile cross-section, in m^4; and

η_h = modulus of subgrade reaction, in MN/m^3 (*see* Table 2).

D-2.3.2 *For Piles in Over-consolidated Clays*

$$\text{Stiffness factor } R\text{, in m} = \sqrt[4]{\frac{EI}{KB}}$$

where

E = Young's modulus of pile material, in MN/m^2;

I = moment of inertia of the pile cross-section, in m^4;

$K = \frac{k_1}{1.5} \times \frac{0.3}{B}$ (*see* Table 3 for values of k_1, in MN/m^3, *see also* Note); and

B = width of pile shaft (diameter in case of circular piles), in m.

NOTE — Table 3 shall be referred if the average unconfined compression strength, q_u is greater than or equal to 100 kN/m^2.

D-3 CRITERIA FOR SHORT RIGID PILES AND LONG ELASTIC PILES

Having calculated the stiffness factor T or R, the criteria for behaviour as a short rigid pile or as a long elastic pile are related to the embedded length L as given in Table 4.

Table 4 Criteria for Behaviour of Pile Based on its Embedded Length

(*Clause* D-3)

Sl No.	Type of Pile Behaviour	Relation of Embedded Length with Stiffness Factor	
		Linearly Increasing	Constant
(1)	(2)	(3)	(4)
i)	Short (rigid) pile	$L \leq 2T$	$L \leq 2R$
ii)	Long (elastic) pile	$L \geq 4T$	$L \geq 3.5R$

NOTE — The intermediate L shall indicate a case between rigid pile behaviour and elastic pile behaviour.

D-4 DEFLECTION AND MOMENTS IN LONG ELASTIC PILES

D-4.1 Equivalent cantilever approach gives a simple procedure for obtaining the deflections and moments due to relatively small lateral loads. This requires the determination of depth of virtual fixity, z_f.

The depth to the point of fixity may be read from the plots given in Fig. 5. e is the effective eccentricity of the point of load application obtained either by converting the moment to an equivalent horizontal load or by actual position of the horizontal load application. R and T are the stiffness factors described in **D-2.3**.

D-4.2 The pile head deflection, y shall be computed using the following equations:

$$\text{Deflection, } y = \frac{H\left(e+z_f\right)^3}{3EI} \times 10^3 \text{ ……. for free head pile}$$

$$\text{Deflection, } y = \frac{H\left(e+z_f\right)^3}{12EI} \times 10^3 \text{ ……. for fixed head pile}$$

where

H = lateral load, in kN;

y = deflection of pile head, in mm;

E = Young's modulus of pile material, in kN/m^2;

I = moment of inertia of the pile cross-section, in m^4;

z_f = depth to point of fixity, in m; and

e = cantilever length above ground/bed to the point of load application, in m.

D-4.3 The fixed end moment of the pile for the equivalent cantilever may be determined from the following expressions:

$$\text{Fixed end moment, } M_F = H\left(e+z_f\right) \text{ ………. for free head pile}$$

$$\text{Fixed end moment, } M_F = \frac{H\left(e+z_f\right)}{2} \text{ ………. for fixed head pile}$$

The fixed head moment, M_F of the equivalent cantilever is higher than the actual maximum moment M in the pile. The actual maximum moment may be obtained by multiplying the fixed end moment of the equivalent cantilever by a reduction factor, m, given in Fig. 6.

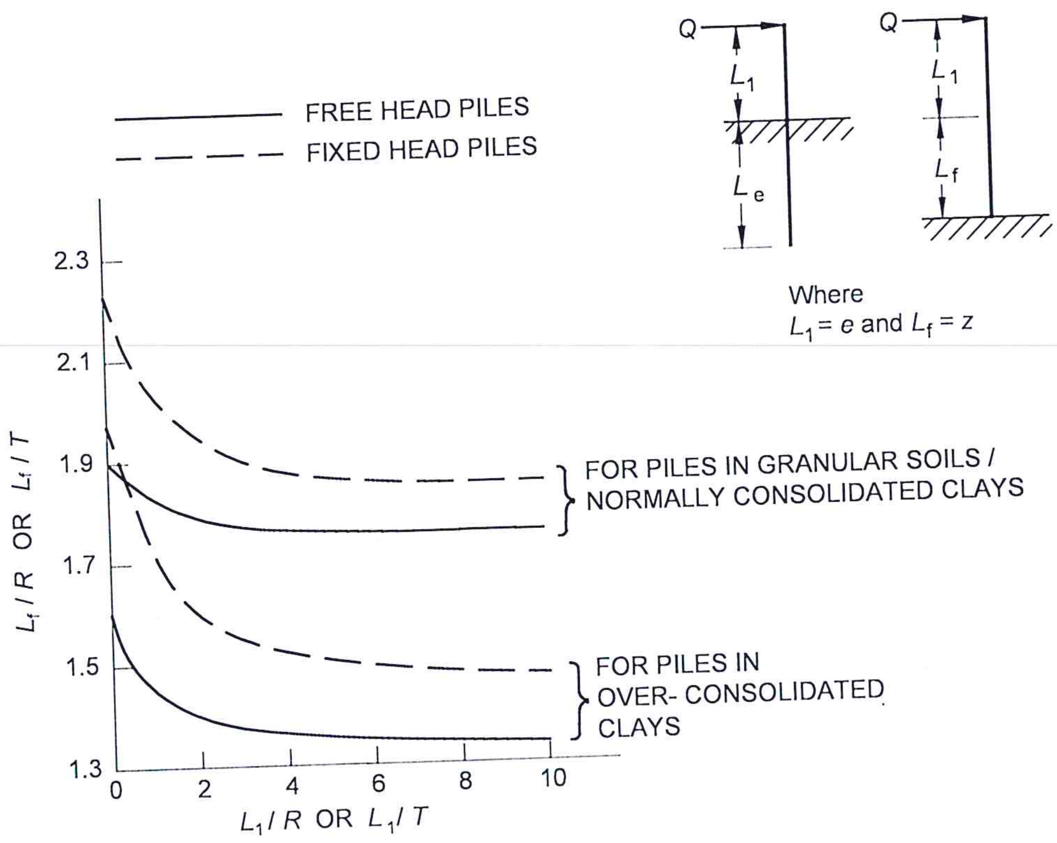
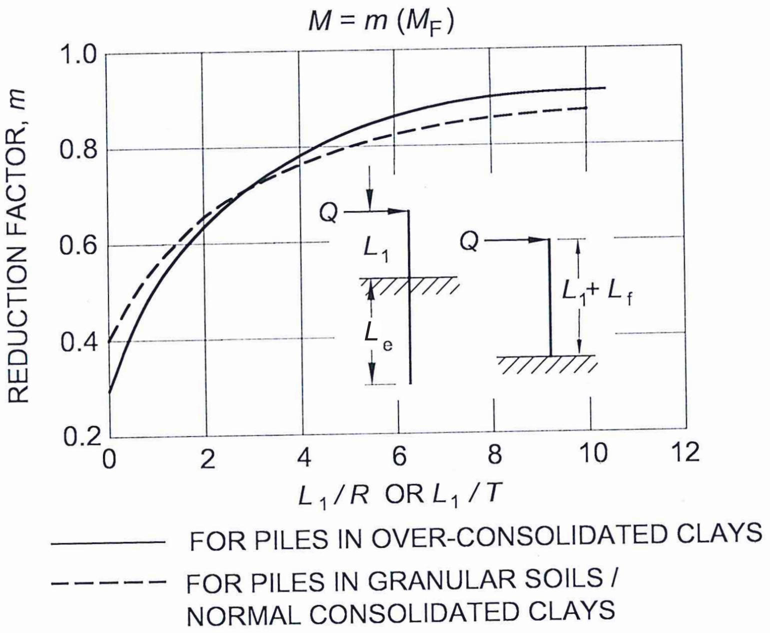
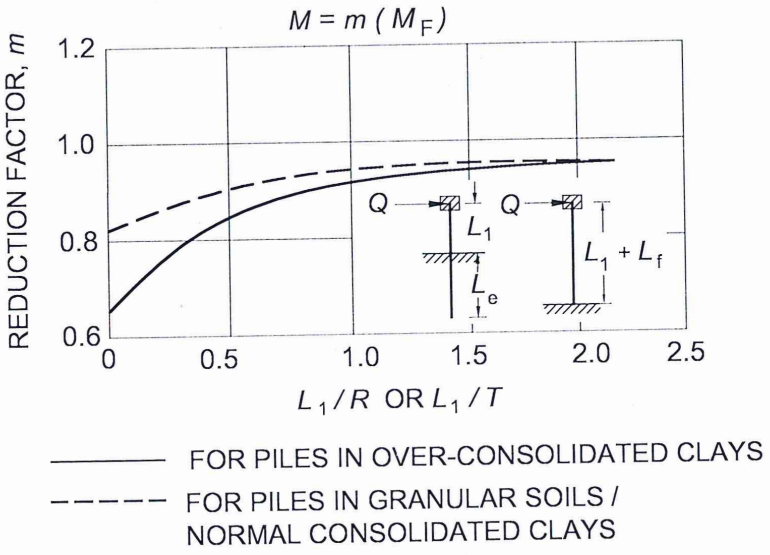


FIG. 5 DEPTH OF FIXITY



6A FOR FREE HEAD PILES



6B FOR FIXED HEAD PILES

FIG. 6 DETERMINATION OF REDUCTION FACTORS FOR COMPUTATION OF MAXIMUM MOMENT IN PILE

ANNEX E

(*Clause* 8.4.1)

REQUIREMENTS OF DRILLING MUD (BENTONITE)

E-1 PROPERTIES

The bentonite suspension used in bore holes is basically a clay of montmorillonite group having exchangeable sodium cations. Because of the presence of sodium cations, bentonite on dispersion will break down into small plate like particles having a negative charge on the surfaces and positive charge on the edges. When the dispersion is left to stand undisturbed, the particles become oriented building up a mechanical structure of its own. This mechanical structure held by electrical bonds is observed as a thin jelly like mass or membrane. When the jelly is agitated, the weak electrical bonds are broken and the suspension becomes fluid again.

E-2 FUNCTIONS

E-2.1 The action of bentonite in stabilizing the sides of bore holes is primarily due to thixotropic property of bentonite suspension. The thixotropic property of bentonite suspension permits the material to have the consistency of a fluid when introduced into a trench or hole. When left undisturbed it forms a jelly like membrane on the borehole wall and when agitated it becomes a fluid again.

E-2.2 In the case of a granular soil, the bentonite suspension penetrates into the sides under positive pressure and after a while, forms a jelly. The bentonite suspension then gets deposited on the sides of the hole and makes the surface impervious and imparts a plastering effect. In impervious clay, the bentonite does not penetrate into the soil, but deposits only as thin film on the surface of hole. Under such condition, stability is derived from the hydrostatic head of the suspension.

E-3 REQUIREMENTS

The bentonite powder and bentonite suspension used for piling work shall satisfy the following requirements:

a) The liquid limit of bentonite when tested in accordance with IS 2720 (Part 5) shall be 400 percent or more.

b) The bentonite suspension shall be made by mixing it with fresh water using a pump for circulation. The density of the freshly prepared bentonite suspension shall be between 1.03 g/ml and 1.10 g/ml depending upon the pile dimensions and the type of soil in which the pile is to be bored. The density of bentonite after contamination with deleterious material in the bore hole may rise up to 1.25 g/ml. This should be brought down to at least 1.12 g/ml by flushing before concreting.

c) The marsh viscosity of bentonite suspension when tested by a marsh cone shall be between 30 to 60 stoke; in special cases it may be allowed up to 90 stoke.

d) The *p*H value of the bentonite suspension shall be between 9 and 11.5.

ANNEX F

(*Clause* 8.9.2)

DATA SHEET

Site ……………………………………………………………………………………...……………………….

Title ……………………………………………………………………………………..……………………….

Date of enquiry………………………………………………………………………...…………………………

Date piling commenced ………………………………………………………………………………………….

Actual or anticipated date for completion of piling work……………………………………………………..

Number of pile ...……………………………………………………………………….

TEST PILE DATA

Pile:	Pile test commenced ………………………………………….…………………….. Pile test completed …………………………………………………………………..
Pile type:	………………………………………………………………………………..... (Mention proprietary system, if any) …………………………………………..........
Pile specification:	Size - Shaft ………………………….……....…Tip ……………………...……….... Bulb(s) Number of Bulbs ……………………………………………………………........ Reinforcement ………………. No. ……………….dia for …………..……….(depth) …………………………………………………………………….. ………………………………………………
Sequence of piling: (for Groups)	From centre towards the periphery or from periphery towards the centre

---

Concrete:	Mix ratio 1: ……………:………………:………………………..by volume/weight or strength after ……………………:…..:….:….. days ……………..:………:....N/mm^2 Quantity of cement/m^3: …………………………………… Extra cement added, if any: ……………………………….

Details of drilling mud used: ……………………………………………………………………………….....

Time taken for concreting: ……………………………………………………………………………………….

Quantity of concrete-Actual: ………………………………………………………………………………………

Theoretical:……………………………………………………….

Test Loading:

Maintained load/Cyclic loading/C.R.P …………………………………………………….………

……………......……………………………………………………………………………….……

Capacity of jack ……………………………………………………………………………..………..…….

If anchor piles used, give……………………………….. No., Length ……………………………………

Distance of test pile from nearest anchor pile ……………………………………………………

Test pile and anchor piles were/were not working piles.

Method of taking observations:

Dial gauges/Engineers level ……………………………………………………………………….....

Reduced level of pile tip …………………………………………………………....………………..

General Remarks:

…………………………………………………………………………………………………….........…

…………………………………………………………………………………...…………………........…

…………………………………………………………………………………………………….........…

…………………………………………………………………………………………………….........…

…………………………………………………………………………………………………….........…

Special difficulties encountered:

…………………………………………………………………………………………………….........…

…………………………………………………………………………………………………….........…

……………………………………………………………………………..............……………………........…..

Results:

Working load specified for the test pile…………………………………………………………......

Settlement specified for the test pile………………………………………………………………......

Settlement specified for the structure ……………………………………………….………………......

Working load accepted for a single pile as a result of the test ....………..……………..........

…………………………………………………………………………………………....…………

……………………………………………………………………………....……………….........…….

Working load in a group of piles accepted as a result of the test……………………......…………………......

....……..……………………………………………………………………………………………..

………………......………………………………………………………………………………………

General description of the structure to be founded on piles……………………………………………......……........

…………………………………………………………………………………………………….........…

…………………………………………………………………………………………………….........…

…………………………………………………………………………………………………….........…

…………………………………………………………………………………………………….........…

…………………………………………………………………………………………………….........…

…………………………………………………………………………………………………….........…

Name of the constructing agency ………………………………………………………………........…….

…………………………………………………………………………………………………….........…

Name of person conducting the test………………………………………………………………........……...

…………………………………………………………………………………………………….........…

Name of the party for whom the test was conducted……………………………………………........……....

…………………………………………………………………………………………………….........…

BORE HOLE LOG

1. Site of bore hole relative to test pile position ……………………………………………………………………
……

2. If no bore hole, give best available ground conditions ………………………………………………………
……
……

Soil Properties	Soil Description	Reduced Level	Soil Legend	Depth Below G.L.	Thickness of Strata
	Position of the tip of pile to be indicated thus → Standing ground water level indicated thus ▽				

METHOD OF SUBSURFACE INVESTIGATION

Trail pit/Post-hole auger/Shell and auger boring/Percussion/Probing/Core-drilling/Shot drilling/Sub-surface sounding by cones or Standard sampler ……………………………………………………………………
……
……
……

Attachments to the report: Graphs, showing the following relations:

a) Load *vs* Time, and

b) Settlement *vs* Load.

ANNEX G

(*Foreword*)

COMMITTEE COMPOSITION

Soil and Foundation Engineering Sectional Committee, CED 43

Organization	*Representative(s)*
In Personal Capacity (*Flat No. 202/395, Jodhpur Park, Kolkata 700068*)	Dr N. Som (***Chairman***)
In Personal Capacity (*D-1903, PWS, 7 Hills, Narsingi(v), Kokapet Road, Ranga Reddy 500089*)	Dr D. N. Naresh (***Vice Chairman***)
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Cengrs Geotechnica Pvt Ltd, Noida	Shri Sanjay Gupta Shri Ravi Sundaram (*Alternate* I) Shri Sorabh Gupta (*Alternate* II)
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Central Designs Organization, Water Resources Deptt, Govt of Maharashtra, Nashik	Superintending Engineer Executive Engineer (*Alternate*)
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Mumbai Port Trust, Mumbai	Dy Chief Engineer (Design) Superintending Engineer (Design) (*Alternate*)

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In Personal Capacity, New Delhi (*Flat No. 220, Ankur Apartments Mother Dairy Road, Patparganj, Delhi 110092*)	Dr V. Thiruvengadam
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Member Secretary

Shrimati Madhurima Madhav
Scientist 'D' (Civil Engineering), BIS

Panel for Review of IS 2911 (Part 3), CED 43 : P7

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(*Continued from second cover*)

This Indian Standard is published in four parts. The other parts in the series are:

Part 1	Concrete piles
Part 2	Timber piles
Part 4	Load test on piles

Part 1 of this standard consists of the following four sections under the general title, Design and construction of pile foundations — Code of practice: Part 1 Concrete piles.

Section 1	Driven cast *in-situ* concrete piles
Section 2	Bored cast *in-situ* concrete piles
Section 3	Driven precast concrete piles
Section 4	Precast concrete piles in prebored holes

In the present revision of this standard (Part 3), the following major modifications have been made:

a) Definitions of various terms have been modified as per the prevailing engineering practices.
b) Use of under-reamed piles of a maximum depth up to 10 m has been permitted.
c) Caution regarding examining the construction feasibility of under-ream/bulb as per soil characteristics, particularly in case of clean/river sand has been added.
d) Procedures for calculation of bearing capacity, structural capacity, factor of safety, lateral load capacity, etc, have also been modified to bring them at par with the present practices.
e) Provisions on overloading and transient loading have been modified.
f) Design parameters with respect to adhesion factor, earth pressure coefficient, modulus of subgrade reaction, etc, have been revised to make them consistence with the outcome of modern research and construction practices.
g) Minimum grade of concrete to be used in under-reamed pile foundations has been revised to M 25.
h) Various provisions on concrete and concreting have been revised based on IS 456 : 2000 'Plain and reinforced concrete — Code of practice (*fourth revision*)'.
j) Requirement for minimum reinforcement has been modified.
k) Need for assessment of liquefaction potential of soil as per IS 1893 (Part 1) : 2016 'Criteria for earthquake resistant design of structures: Part 1 General provisions and buildings (*sixth revision*)' has been included.
m) Caution regarding use of safe load tables has been added and the provisions in the table have been modified.

In the formulation of this standard due weightage has been given to international co-ordination among the standards and practices prevailing in different countries for pile foundations, in addition to relating it to the practices in the field in this country.

The composition of the Committee responsible for the formulation of this standard is given in Annex G.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

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Amendments Issued Since Publication

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